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EVALUATION OF HIGH ACCURACY PRODUCTS CORPORATION MODEL PC-202 AUTOMATIC PARTICLE COUNTER

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MATERIALS DIVISION
PROPULSION AND VEHICLE ENGINEERING LABORATORY

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ABSTRACT

In a previous investigation, it was shown that the HIAC Model 101 automatic particle counter gave excellent results for laboratory samples. However, marked discrepancies were noted between in-line automatic counter results and those determined microscopically for samples withdrawn from the system through a bleed valve.

To obtain further information on in-line monitoring of particulate contaminant, an improved HIAC counter (Model 202) was used to obtain in-line data for comparison with microscopic results for samples withdrawn from the system through an improved sampling arrangement. The results indicated that with suitable operating procedures the Model 202 counter gives results generally equivalent to those determined microscopically.

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SUMMARY

In a previous investigation, it was shown that the HIAC Model 101 automatic particle counter gave excellent results for laboratory samples. However, marked discrepancies were noted between in-line automatic counter results and those determined microscopically for samples withdrawn from the system through a bleed valve.

To obtain further information on in-line monitoring of particulate contaminant, an improved HIAC counter (Model 202) was used to obtain in-line data for comparison with microscopic results for samples withdrawn from the system through an improved sampling arrangement. The results indicated that with suitable operating procedures the Model 202 counter gives results generally equivalent to those determined microscopically.

The standard deviations for both microscopic and automatic results closely approached values predicted theoretically by means of the Poisson equation. This confirms the expectation that for a system with a uniform level of contamination and adequate sampling methods the reproducibility of results is determined almost entirely by the number of particles counted.

INTRODUCTION

Although the microscopic method currently is accepted as the standard for determining the level of particulate contamination in fluid systems, it has a number of undesirable characteristics. Specifically, the microscopic method is time consuming, involves a significant element of personal judgment, does not reproduce adequately, and is not adaptable to in-line monitoring of continuously operating systems. Therefore, this laboratory is investigating various types of automatic counting devices. In a previous investigation (Ref. 1), it was found that for laboratory samples the High Accuracy Products Corporation (HIAC) Model 101 Automatic Particle Counter gave results that were virtually identical to those determined microscopically on the same sample. However, in-line results with this counter differed markedly from those obtained microscopically for samples taken from an ordinary bleed valve located just upstream of the counter. The cause of the discrepancy was not established, but it was considered evident that either the samples withdrawn for laboratory analysis or that portion of the total flow diverted through the counter for automatic monitoring was not representative of the average contamination level in the system. Also, it was noted that the relatively small flow rate through the counter ($\approx$ 1 ml/min) severely restricted the rate at which analyses could be made.

Because of these reasons, a further investigation was carried out using a High Accuracy Products Corporation Model 202 Counter. This counter was a later model than that previously investigated and could accommodate flow rates up to 35 ml per minute. The counter was fitted with a Maledco turbulent flow sampling valve to insure that the portion of the total flow diverted through the counter for monitoring was representative of the average concentration in the system. Also, for this study, the bleed valve used to obtain laboratory samples was relocated to provide more representative samples for microscopic analysis.

This report presents the results of the investigations carried out with the Model 202 Counter and includes results obtained previously with the Model 101 Counter which are directly applicable to the Model 202 Counter.

EXPERIMENTAL

The experimental setup (FIG 1) consisted of a hydraulic test cart, associated plumbing, and the HIAC Model PC 202 Particle Counter. The test cart, containing a 30-gallon reservoir, flow meters, pressure gauges, and filters, was modified so that the system fluid could either be circulated through the filters for cleanup or by-passed to maintain approximately uniform contamination levels during testing operations. When a test was carried out, the fluid was circulated through the test cart and system until the desired operating temperature, pressure, flow rate, and uniform contamination level were obtained. The operating conditions and particle count data for each test are summarized in

Table I. Six contamination levels are studied: the first was obtained by cleaning the hydraulic fluid to the lowest contamination level possible using the system filters; the other levels were obtained by introducing contaminated hydraulic fluid into the system reservoir to augment each preceding test level.

The Model PC-202 Counter was equipped with metering pistons and associated circuits for automatic in-line monitoring. When the counter was in operation, the fluid sample passed through the counting cell at flow rates up to 35 ml per minute and pressures up to 500 psi. Under these conditions, the flow characteristics were such that each solid particle passed an illuminated window in single file. Light was collimated and directed through the fluid stream to impinge on a phototube on the opposite side; when a particle in the fluid stream passed the window, a portion of the light beam was interrupted. This created a change in the output signal from the photo-tube which was proportional to the size of the particle. The change in signal was amplified and sent to counter circuits that had been adjusted to various sensitivities for simultaneous counting of individual size ranges. The particles then were tallied according to size. After passing through the cell, the sample was metered into a precision measuring piston so that the results could be recorded as number of particles per volume of fluid.

The counter was calibrated by use of the "built-in" calibration system that consisted of an interrupter disc driven by an electric motor, calibration potentiometer, light source, and calibration window (Ref. 2). The transparent interrupter disc had a scribed opaque radial line that was slightly wider than the calibration window through which the light was focused. Thus, for each revolution of the interrupter disc, the light was completely blocked when the radial line passed the calibration window. Since the calibration window area was known, the percent change in photo-tube output produced by a particle of given size could be calculated. The calibration potentiometer was used to select the desired particle size calibration. Suggested particle size calibration values were furnished by the manufacturer for use with the "built-in" calibration system.

The Model 202 Particle Counter, equipped with a C-150 microcell, was capable of monitoring four individual particle size ranges from 10 to 150 microns at 100-ml increments with printed read-out and using either the manually operated or the automatic sampling arrangement. For this investigation, the four selected size ranges were monitored simultaneously for approximately three-minute intervals at 35 ml per minute sample flow rate. However, the total testing time was approximately five minutes per sample since the sample fluid that collected in the metering piston had to be removed by a back flushing operation. The sampling and back flushing operations were accomplished automatically by using solenoid valves actuated by relay switches that were located at opposite ends of the metering piston. After the sample had accumulated in the metering piston, the solenoid valves were actuated to return the sample to the system. The printer also was actuated automatically at the completion of each metering piston sampling stroke.

All microscopic analyses were made in accordance with MSFC-PROC-166A, "Procedure for Cleaning, Testing, and Handling of Space Vehicle Hydraulic System Components and Hydraulic Fluids," except the method of counting particles in the smaller size ranges where the total number of particles retained on the Millipore membrane were not always counted. In these instances, only the particles retained on one or two diametric scans (microscopic micrometer scale width x effective filtration diameter of filter paper) were counted. The number of scans examined was selected to give a minimum of 100 particles for each size range.

DISCUSSION OF RESULTS

Results obtained during this investigation for both microscopic and automatic (Model 202) counts are given in Table I. The mean values and standard deviations for each of the six contamination levels studied are given in Table II.

The reproducibility of counting data is dependent on the number of particles actually counted. Therefore, calculation of the reproducibility of the data in terms of standard deviations was based on the actual number of particles counted in all instances. Standard deviations for the HIAC and microscopic counts are shown in FIG 2 and 3 with the lines determined previously for microscopic counts on samples from hydraulic systems (Ref. 3) and theoretical values representing the standard deviations for a Poisson distribution. Since the earlier investigation was made using ground service hydraulic systems for which the contamination levels varied, contribution from this source would be expected to be smaller with the hydraulic test cart used in this investigation. In agreement with this expectation, FIG 2 indicates that the standard deviations for both the HIAC and microscopic counts generally were smaller than the corresponding microscopic values reported previously. In fact, except for the highest counts, the determined values scattered more or less uniformly about those predicted theoretically by means of the Poisson equation. This suggests that in the current investigation variations due to system fluctuations have been largely eliminated, and the observed variations are generally indicative of those inherent to the test method.

In the previous investigation using the Model 101 Counter, it was shown that microscopic counts on portions of hydraulic fluid collected after passing through the counting cell were virtually identical to the automatic counts. In fact, it was shown that the small systematic deviations noted between the microscopic and automatic counts probably resulted because the automatic counts were based on equivalent circle diameters, and the microscopic counts were based on longest dimensions of the particles. By cross-plotting the counting data, equivalent circle diameters corresponding to the class boundaries for the MSFC acceptable contamination levels were determined. Confirmation of these values was obtained by microscopic determinations of equivalent circle diameters and longest dimensions for some 500 particles of various sizes. Because of the similarities in the two counters, equivalent results would be expected with the Model 202 Counter. Thus, this part of the investigation was not repeated.

In contrast to the excellent agreement determined with the microscopic and automatic counts made on the identical fluid sample, automatic counts obtained by diverting a portion of the total flow through the Model 101 Counter differed markedly from the microscopic counts obtained by withdrawing a laboratory sample from a bleed valve attached to the side opening of a horizontally positioned bleed valve located just upstream of the counter. Studies of sampling valves carried out after the investigation of the Model 101 Counter suggested that probably neither the automatic nor the microscopic counts were representative of the average contamination level in the system because of sampling problems. For this reason, the evaluation of the suitability of the HIAC Counter for in-line monitoring was re-investigated by using the improved Model 202 Counter and an improved arrangement for in-line sampling.

The corresponding microscopic and Model 202 Counter results for the different contamination levels are presented in FIG 4. Average values for these same data are cross-plotted in FIG 5. When this part of the investigation was carried out, the equivalent circle diameter class boundaries for the Model 202 Counter corresponding to the microscopic longest dimension class boundaries were the values determined previously (Ref. 1) by cross-plotting counting data obtained automatically and microscopically on the identical fluid samples. Although it was recognized that the exact relation between equivalent circle diameter and longest dimension varies with the origin and type of contaminant tested, the previous investigation, like the current one, utilized contaminated hydraulic fluid to adjust system contamination levels. Therefore, the determined class boundaries should be applicable to the current investigation. These values were as follows:

Class Boundaries, Microns

Microscopic (Longest Dimension)	Model 202 Counter (Equivalent Circle Diameter)
10-25	10.9 - 21.0
25-50	21.0 - 40.0
50-100	40.0 - 75.0
>100	>75.0

Straight lines passing through the origin were fitted to the data by the method of least squares. Equations for each size range are given in Table III with the standard errors for values calculated with the equation. Also included in Table III are identity equations of the type y=x and the corresponding root-mean-square deviation for each size range. Inspection of these data indicates that the slopes of the least square equations generally are close to unity, and the standard errors for values calculated with the least squares equation are only slightly smaller than the corresponding root-mean-square deviations for the identity equations. For these reasons, straight lines passing through the origin and having unit slopes corresponding to the identity equations are shown in FIG 4. Inspection of the plotted points indicates that the microscopic and Model 202 Counter results are virtually identical for the three smallest size ranges; the microscopic results generally exceeded the Model 202 Counter results for the largest ($>100\mu$) size range, particularly for the lower contamination levels. A review of the sampling arrangement suggested that this discrepancy may have been caused by failure of the bleed valve to provide representative samples for this size range because of the greater momentum of the particles. Further studies using a Maledco or similar sampling valve to withdraw samples for microscopic analyses are needed to resolve this question. However, the discrepancy is not great, and, in general, it appears that with suitable operating procedures the Model 202 Counter provides results equivalent to those obtained microscopically.

CONCLUSIONS

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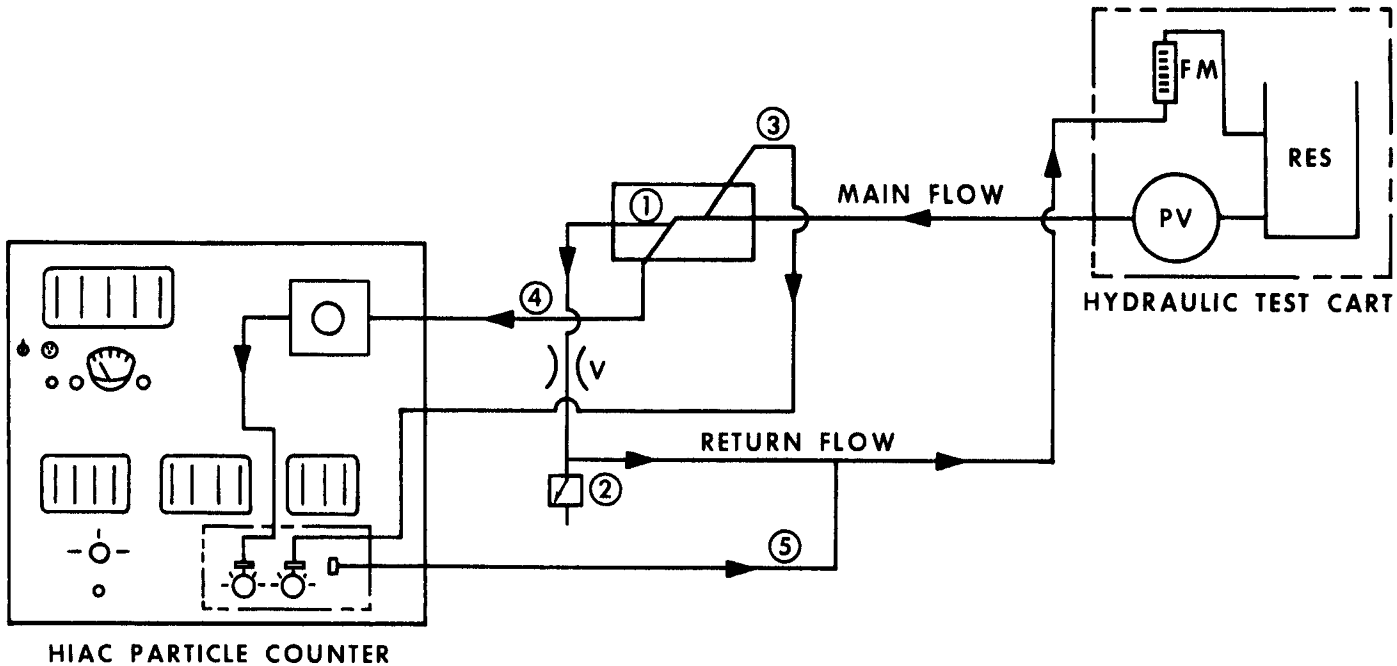
The HIAC Model 202 Automatic Particle Counter gives results which appear to be generally equivalent to those obtained microscopically.

The reproducibility of particle counts for replicate samples taken from a well-regulated system approaches the values predicted theoretically by means of the Poisson equation. Therefore, the theoretical values reflect the inherent variability of the test results and constitute the lower limit for determined values.

Author



① MALEDCO TURBULENT FLOW SAMPLING VALVE (2.6-6.0GPM)
② BLEED VALVE USED FOR WITHDRAWING SAMPLES FOR MICROSCOPIC COUNTS
③ LINE FOR SUPPLYING SYSTEM PRESSURE TO METERING PISTON FOR BACK FLUSHING OPERATION
④ LINE FOR SUPPLYING SAMPLE FLUID TO HIAC COUNTER, ALSO RETURN LINE FOR BACK FLUSHING OPERATION
⑤ LINE FOR EMPTYING FLUID FROM METERING PISTON DURING SAMPLING OPERATION

FIGURE 1 TEST ARRANGEMENT

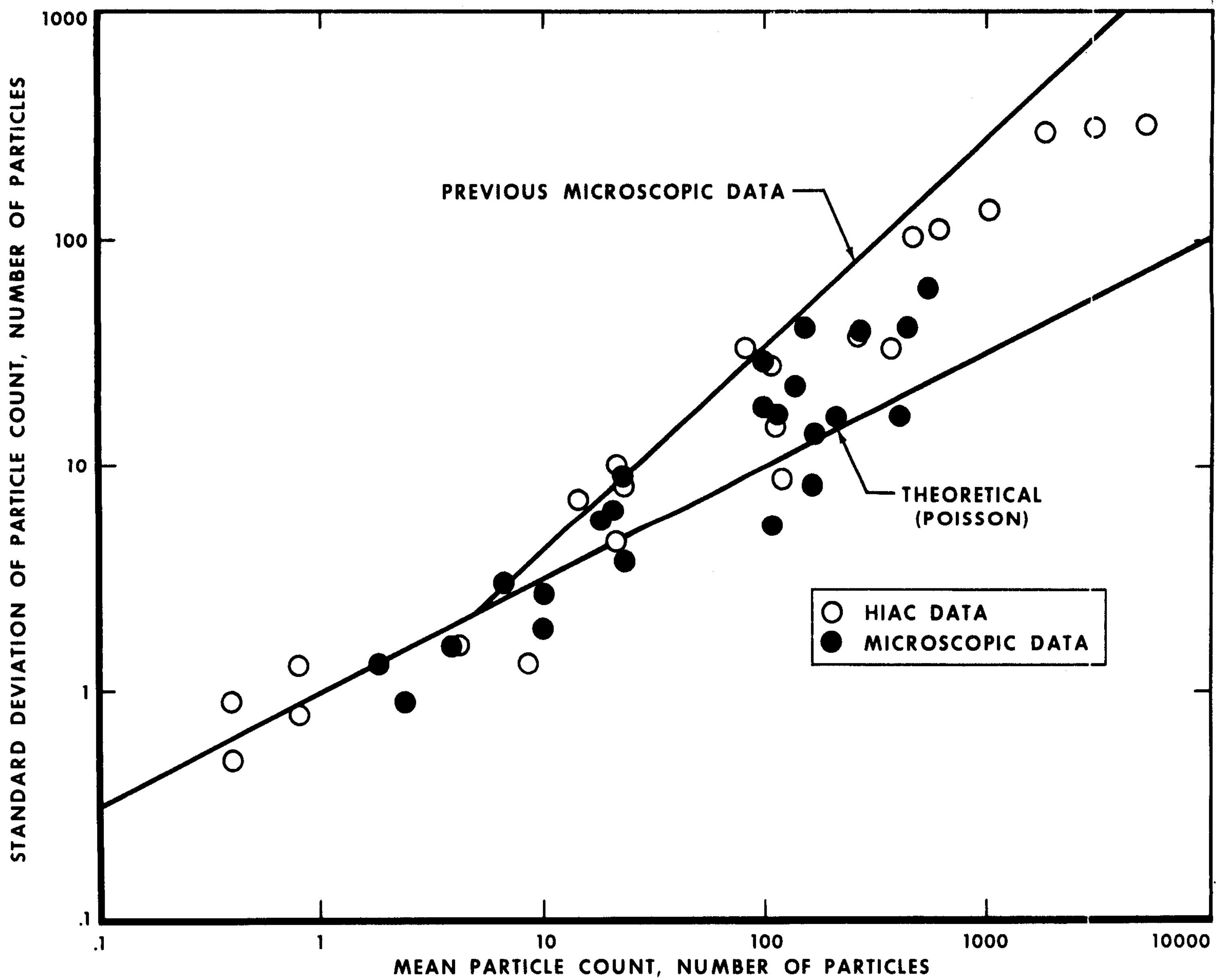


FIGURE 2 COMPARISON OF STANDARD DEVIATIONS FOR HIAC AND MICROSCOPIC COUNTS WITH THEORETICAL VALUES

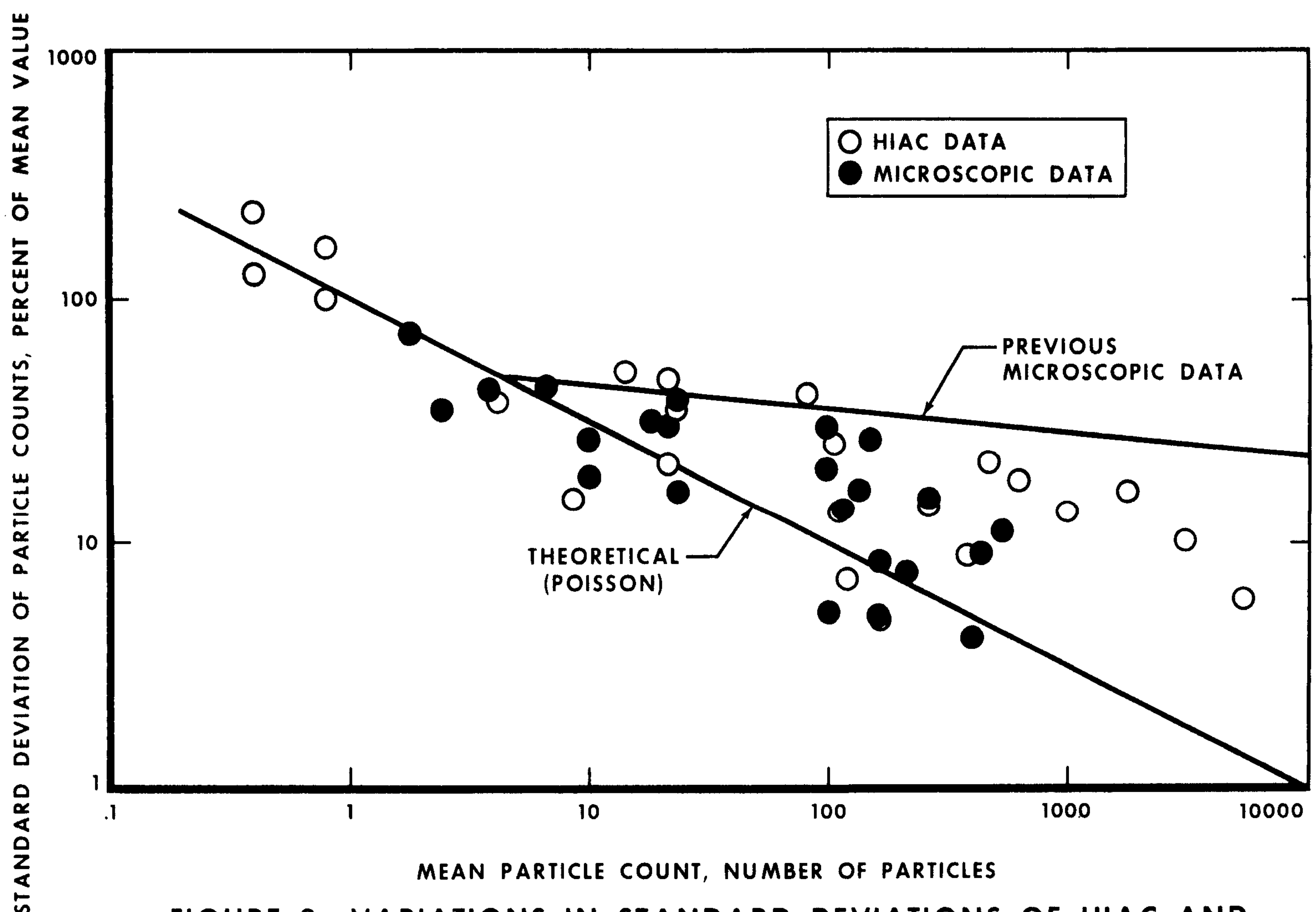


FIGURE 3 VARIATIONS IN STANDARD DEVIATIONS OF HIAC AND MICROSCOPIC PARTICLE COUNTS WITH NUMBER OF PARTICLES COUNTED

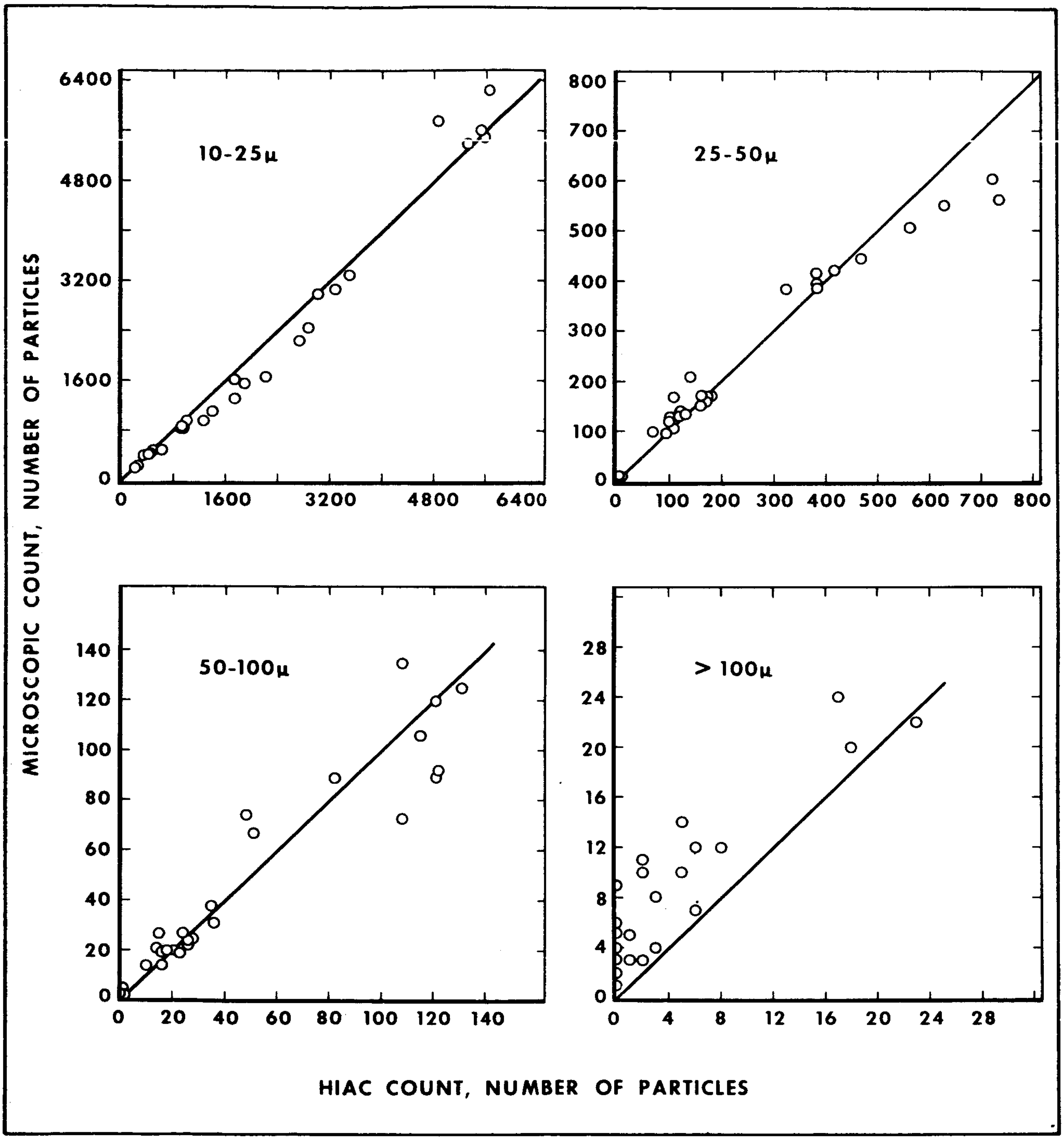


FIGURE 4 COMPARISON OF MICROSCOPIC AND HIAC MODEL PC 202 PARTICLE COUNTS

TABLE I. SUMMARY OF HIAC MODEL PC 202 AND MICROSCOPIC RESULTS

SIZE RANGE, MICRONS	10 - 25		25 - 50		50 - 100		>100		TEST CONDITIONS*	
COUNT METHOD	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	SYSTEM PRESSURE PSI	SYSTEM FLOW RATE GPM
Sample #										
1	222	196	8	11	1	4	0	0		
2	285	232	10	8	0	1	0	0		
3	294	233	7	11	0	1	0	0	500	4.0
4	285	214	10	8	0	2	0	0		
5	222	205	8	12	1	1	0	0		
1	611	483	161	171	36	31	3	4		
2	421	415	159	152	16	14	1	5		
3	343	398	169	159	23	19	0	1	400	5.0
4	455	431	174	165	26	22	0	5		
5	512	488	179	171	16	19	0	4		
1	947	866	100	120	23	19	0	3		
2	928	814	93	96	15	27	0	1		
3	1250	972	131	135	26	24	0	3	400	5.0
4	1014	979	109	107	24	27	2	3		
5	941	824	117	131	18	20	0	2		
1	1400	1102	323	385	122	92	5	14		
2	1727	1295	382	387	131	125	5	10		
3	1726	1605	381	415	115	106	3	8	400	5.4
4	1874	1562	415	421	121	89	2	11		
5	2202	1668	383	396	108	73	6	7		
1	3489	3295	139	210	35	38	1	5		
2	3266	3071	108	169	28	25	0	6		
3	3019	2996	122	145	21	20	2	10	400	5.4
4	2863	2447	100	131	14	21	0	9		
5	2718	2193	65	101	10	14	1	3		
1	4861	5778	734	561	108	135	23	22		
2	5656	6242	722	604	121	120	17	24		
3	5518	5617	627	551	82	89	18	20	400	3.6
4	5582	5510	562	506	48	74	6	12		
5	5318	5403	466	444	51	67	8	12		

*FLUID TEMPERATURE FOR THESE TESTS WAS MAINTAINED AT $100 \pm 5^{o}F$.

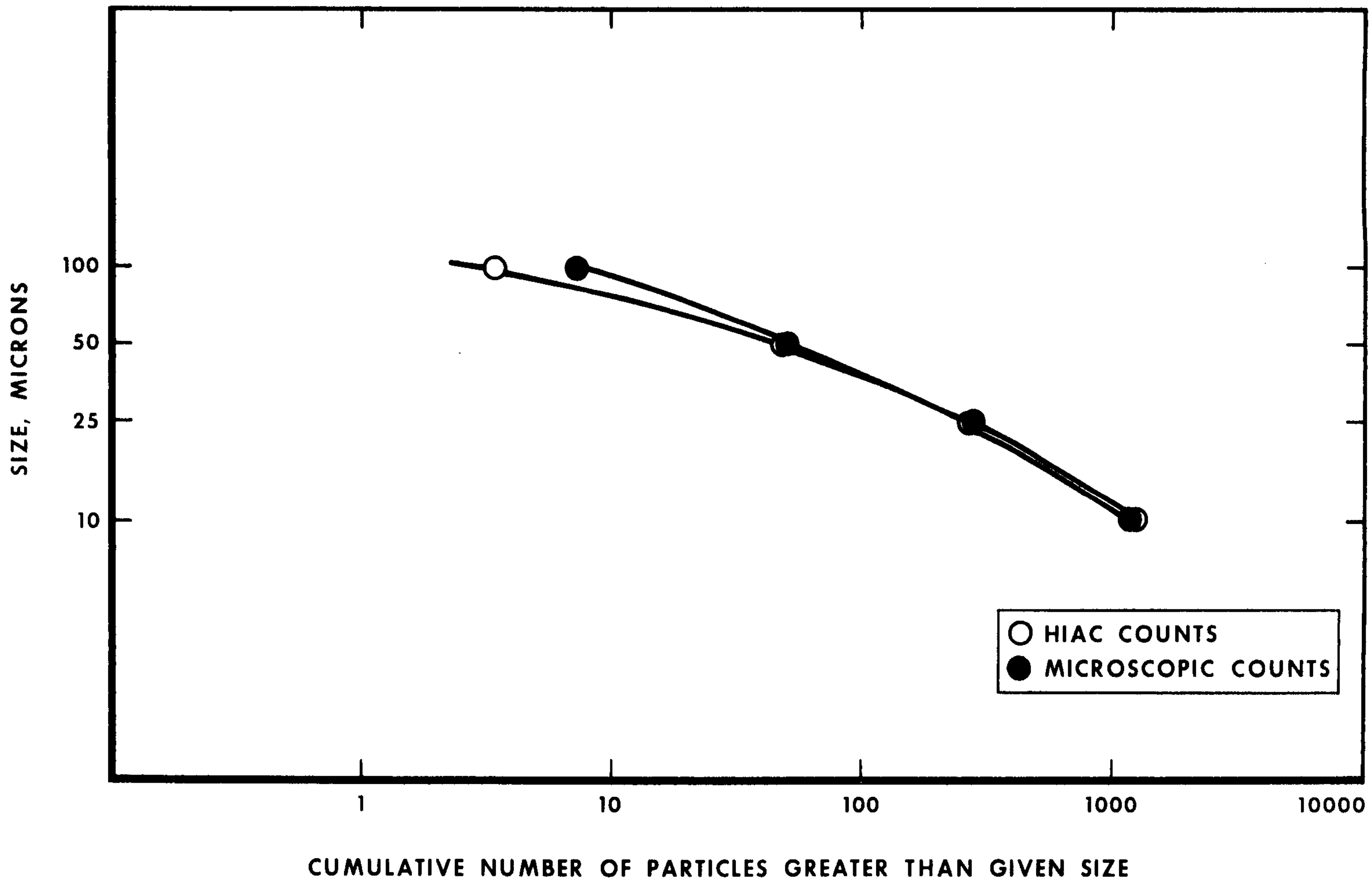


FIGURE 5 AVERAGES OF 30 MICROSCOPIC AND 30 HIAC COUNTS

TABLE I. SUMMARY OF HIAC MODEL PC 202 AND MICROSCOPIC RESULTS

SIZE RANGE, MICRONS	10 - 25		25 - 50		50 - 100		>100		TEST CONDITIONS*	
COUNT METHOD	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	SYSTEM PRESSURE PSI	SYSTEM FLOW RATE GPM
Sample #										
1	222	196	8	11	1	4	0	0		
2	285	232	10	8	0	1	0	0		
3	294	233	7	11	0	1	0	0	500	4.0
4	285	214	10	8	0	2	0	0		
5	222	205	8	12	1	1	0	0		
1	611	483	161	171	36	31	3	4		
2	421	415	159	152	16	14	1	5		
3	343	398	169	159	23	19	0	1	400	5.0
4	455	431	174	165	26	22	0	5		
5	512	488	179	171	16	19	0	4		
1	947	866	100	120	23	19	0	3		
2	928	814	93	96	15	27	0	1		
3	1250	972	131	135	26	24	0	3	400	5.0
4	1014	979	109	107	24	27	2	3		
5	941	824	117	131	18	20	0	2		
1	1400	1102	323	385	122	92	5	14		
2	1727	1295	382	387	131	125	5	10		
3	1726	1605	381	415	115	106	3	8	400	5.4
4	1874	1562	415	421	121	89	2	11		
5	2202	1668	383	396	108	73	6	7		
1	3489	3295	139	210	35	38	1	5		
2	3266	3071	108	169	28	25	0	6		
3	3019	2996	122	145	21	20	2	10	400	5.4
4	2863	2447	100	131	14	21	0	9		
5	2718	2193	65	101	10	14	1	3		
1	4861	5778	734	561	108	135	23	22		
2	5656	6242	722	604	121	120	17	24		
3	5518	5617	627	551	82	89	18	20	400	3.6
4	5582	5510	562	506	48	74	6	12		
5	5318	5403	466	444	51	67	8	12		

*FLUID TEMPERATURE FOR THESE TESTS WAS MAINTAINED AT $100 \pm 5^{o}F$.

TABLE II. SUMMARY OF REPRODUCIBILITY OF RESULTS[1] OBTAINED FOR HIAC AND MICROSCOPIC SAMPLES

SIZE RANGE, MICRONS	10 - 25		25 - 50		50 - 100		> 100	
COUNT METHOD	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC	HIAC	MICROSCOPIC
Mean	261.6	216.0	8.6	10.0	0.4	1.8	0.0	0.0
Standard Deviation	36.3	16.4	1.3	1.9	0.5	1.3	0.0	0.0
Mean	468.4	443.0	168.4	163.6	23.4	21.0	0.8	3.8
Standard Deviation	100.5	40.6	8.5	8.2	8.3	6.3	1.3	1.6
Mean	1016.0	165.8[2]	110.0	117.8	21.2	23.4	0.4	2.4
Standard Deviation	135.0	14.0	14.8	16.3	4.5	3.8	0.9	0.9
Mean	1785.8	135.4[2]	376.8	400.8	119.4	97.0	4.2	10.0
Standard Deviation	290.2	22.6	33.3	16.4	8.6	19.6	1.6	2.7
Mean	3071.0	263.8[2]	106.8	151.2	21.6	23.6	0.8	6.6
Standard Deviation	309.6	39.8	27.7	41.1	10.2	9.0	0.8	2.9
Mean	5387.0	106.4[2]	622.2	533.2	82.0	97.0	14.4	18.0
Standard Deviation	319.8	5.5	112.4	60.8	32.8	29.4	7.2	5.7

[1] All values based on results for five samples.

[2] Microscopic results for the 10-25 μ size range are the actual number of particles counted on millipore membrane where the total number was not counted.

TABLE III

EQUATIONS RELATING MICROSCOPIC AND HIAC COUNTS

Size Range, Microns	Least Squares Equations	Identity Equations
10-25	MC = 1.002 HC SMC = 296 particles or 16 percent*	MC = HC RMC = 296 particles or 16 percent*
25-50	MC = 0.921 HC SMC = 43 particles or 19 percent*	MC = HC RMC = 50 particles or 21 percent*
50-100	MC = 0.934 HC SMC = 13 particles or 29 percent*	MC = HC RMC = 14 particles or 31 percent*
>100	MC = 1.250 HC SMC = 4 particles or 58 percent*	MC = HC RMC = 5 particles or 75 percent*

MC = Microscopic count, number of particles

HC = HIAC count, number of particles

SMC = Standard error for microscopic count calculated from HIAC count for least squares equation

RMC = Root-Mean-Square deviation for microscopic count calculated from HIAC count for identity equation

*Based on average microscopic count.

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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